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The re-emergence of transport costs as an influence on industrial location within a low carbon economy

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Abstract

Mitigating the impact of human induced climate change will result in fundamental changes to the global economy, notably a transition from fossil fuels to renewable sources of energy generation. Akin to fossil fuels, the distribution of renewable energy resources is geographically asymmetric. Whilst declining transport costs for freight, from the beginning of the nineteenth century onwards, have diminished the importance of proximity between industrial location and natural resource location, the "death of distance" may not apply so readily to renewable energy resources. Transporting renewable energy is relatively expensive, thereby challenging the economics of transporting both raw materials and energy to centralised industrial hubs. Ceteris paribus, barriers to transporting renewable energy alter the dynamics of industrial location and provide a competitive advantage for regions containing an abundance of low-cost renewable energy resources. Future modelling of industrial location, industrial policy and corporate strategy would benefit from acknowledging this dynamic.

Keywords: Location Theory, Spatial Economics, Economic Geography, Climate Change, Renewable Energy, Industrial Strategy, Comparative Advantage, Global Value Chains.

1. Introduction

Geography and economics are intertwined. Traditionally, economic activity has been heavily influenced by the location of natural resources, leading to the establishment of important port, river, mining and agricultural centres across the planet. This was due to the traditional barrier imposed by high transport costs for goods. Through time, technological advancements have enabled freight costs to fall dramatically leading Glaeser and Kohlhase (2004) to argue that industrial location is no longer dependent on natural resources. Instead, modern economies are characterised by agglomeration forces, where cities are growing in environmentally attractive regions to facilitate the movement of knowledge and ideas.

Efforts to cut greenhouse gas emissions and address human induced climate change are likely to challenge arguments pertaining to the redundancy of transport costs. Replacing fossil fuels requires rapid uptake of renewable forms of energy generation. Whilst transport costs over intercontinental distances for fossil fuels, such as coal and oil, are negligible, the same cannot be said for shipping renewable forms of energy (Sørensen & Spazzafumo, 2018). Given that renewable energy is both asymmetrically distributed and expensive to ship, regions with an abundance of low-cost renewable energy are well placed to become global centres of energy intensive manufacturing and minerals processing (Garnaut, 2019).

This has major implications for industrial location theory in a low-carbon economy. Future industrial location models will benefit from the addition of a trade-off between locating production adjacent to renewable energy resources and the cost of transporting renewable energy to existing industrial hubs. With sentiment to curtail global emissions approaching a tipping point, the dynamics discussed in this paper are becoming increasingly relevant to both companies and policymakers. Carbon border taxes, designed to level the playing field between nations with different emissions standards, are on the horizon (BCG, 2020). This will have a profound impact on firms which need to find means of "greening" their supply chains in the face of more stringent environmental regulations and consumer pressure.

2. Transport Costs: A Story of Decline

Since the nineteenth century, regional economics and industrial location theory have evolved considerably. Early models developed by Ricardo (1817) and von Thünen (1826) explained agricultural land use as a function of distance from a market. Activities which are perishable or incur higher transportation costs locate closer to consumers. These principles were enhanced in the Bid-Rent model which enabled the substitution of land and non-land production factors (Alonso, 1964; Mills, 1969; Muth, 1969). In response to the dominance of industry over agriculture in major economies at the turn of the twentieth century, Weber (1909) proposed an industrial location model which traded-off the effects of transport, labour and agglomeration. These factors were incorporated into the NEG model which gained widespread acceptance by economists. It suggested that firms would locate based on the cost of labour, market size, transport costs and the influence of agglomeration economies (increasing returns to scale) (Krugman, 1991). Global value chains have demonstrated the benefits of locating functions across the globe to exploit locational advantages such as low-cost labour, minimal environmental regulations, mineral resources, highly skilled labour and liquid capital markets (McWilliam et.al, 2020; Ambos et.al, 2021).[1]

A unifying element of location theory has been its focus on the transport costs of manufactured or physical goods (Rietveld & Vickerman, 2004). For most of human history, transport costs for physical goods posed a significant barrier. This had a profound impact on urban and regional form. Moving a tonne of coal just 100 kilometres using a horse and cart took several days and required manual loading and unloading at both the origin and destination. To enable more efficient transportation, settlements and industry tended to locate in proximity to natural waterways such as rivers, lakes and ports. This is evidenced by the location of traditional centres in the United Kingdom and United States such as London, Bristol, New York, Baltimore and Chicago.[2] Technological breakthroughs in canal building resulted in a significant drop in transport costs within inland areas. For instance, the Bridgewater Canal,

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[1] A homogenous set of global climate and environmental standards would be ideal. In its absence, corporations may locate pollutive activities in countries with lower standards to reduce costs. Tariffs on imports from regions with lower standards help level the playing field and reduce market failure. In the long run, nations with lower standards are likely to fall behind technologically, as stringent and continuously improved standards promote greater levels of innovation (Friedman & Mandelbaum, 2011). Nations which are slow to act on emissions reduction may also bear political costs.

[2] A similar pattern is found in most countries.

which opened in 1761 to link coal fields with major industry, halved the cost of coal in Manchester within its first year of operation (Peel Holdings, 2021). The success of the canal led to a rapid period of canal construction across Europe and North America which remained unrivalled until the emergence of railways in the early nineteenth century.

Falling transport costs for goods have continued into the twentieth and twenty-first centuries. Railways have become more efficient, containers have reduced handling times, ships have grown considerably, and automation has enabled more efficient loading and unloading of cargo. Taken together, these forces have resulted in the argument that transport costs for physical goods are redundant (Cairncross, 1997; Glaeser & Kohlhase, 2004).

According to data from the Census' Historical Statistics of the United States and the Bureau of Transportation Statistics, the cost of transporting a tonne of goods one mile by rail in the United States fell from 19c in 1890 to just 2.3c in 2000. Maritime shipping costs also fell by about 84 per cent between 1750 and 1990 as larger ships, containerisation and automation drastically lifted efficiency (Jacks & Pendakur, 2010; Rietveld & Vickerman, 2004; Venables & Crafts, 2001). This has resulted in transport's share of gross domestic product plummeting from 8 per cent in 1929 to 3 per cent by 1990. Removal of air transport, which is primarily utilised for the transportation of people, decreases transport's share of the economy to approximately 2 per cent in 2019 (ABS, 2020).

Declines in transport costs have shaped modern industrial location and enabled production to relocate away from natural resources to locations where operating costs are lower (Mudambi, 2018). For example, Australian iron ore is shipped to facilities in China, smelted using energy generated from Australian coal and returned to Australia as steel at a lower price than if it was processed in Australia. This is because freight costs for iron ore are approximately AUD $4 tonne for the nation's leading miners, BHP and Rio Tinto (Heber, 2015). With an iron ore spot price of AUD $220 per tonne on 12 January 2021, transport costs account for well under 2 per cent of the commodity's value.[3]

3. The Influence of Climate Change

Limiting global average temperature to two degrees above pre-industrial levels, in accordance with the 2015 Paris Climate Agreement (Paris Agreement, 2015), requires developed economies to reach net zero emissions before 2050. This will necessitate energy intensive activities, such as transportation, manufacturing and minerals processing, to be switched from fossil fuels to renewable sources of energy (Ge, 2020). A transition to renewables of this magnitude will disrupt contemporary value chains which rely on the transportation of fossil fuel energy from resource rich nations to factories in Asia. Examples include Australia, which exports about 380 million tonnes of coal each year (RBA, 2020), and middle eastern oil nations, that export over 5 million barrels of oil per annum (Statistica, 2019). Low transport costs mean that coal prices in Japan, Korea and China are on par with those in Australia.

Akin to fossil fuels, renewable energy resources are asymmetrically distributed. This is reflected in data from the National Renewable Energy Laboratory which estimate the potential wind and solar energy resources of world economies. Wind and solar energy are emphasised, given the limited scope for expansion of hydroelectricity without unacceptable levels of

[3] Iron ore spot price is converted to AUD using the exchange rate taken on 12 January 2021.

environmental damage. Further, time taken to recapture biofuel emissions and the energy source's opportunity cost on land are likely to limit its use to specific functions such as jet fuel.

National Renewable Energy Laboratory data reveal that major economies, such as Russia, the United States, China, Brazil, Canada and Australia are well endowed with wind and solar energy potential (National Renewable Energy Laboratory, 2020a, 2020b). On a per capita basis, Australia and Canada are particularly well placed; a position which is strengthened by access to developed capital markets, strong institutions and an educated workforce. This suggests that it will be easier for some nations to achieve net zero emissions.

Unlike fossil fuels, which have high energy density, renewable sources of energy are expensive to transport over very long distances. The two primary options: high voltage direct current and green hydrogen, either compressed hydrogen or liquified ammonia, remain poor substitutes relative to the economies achieved in the transportation of fossil fuels over equivalent distances.

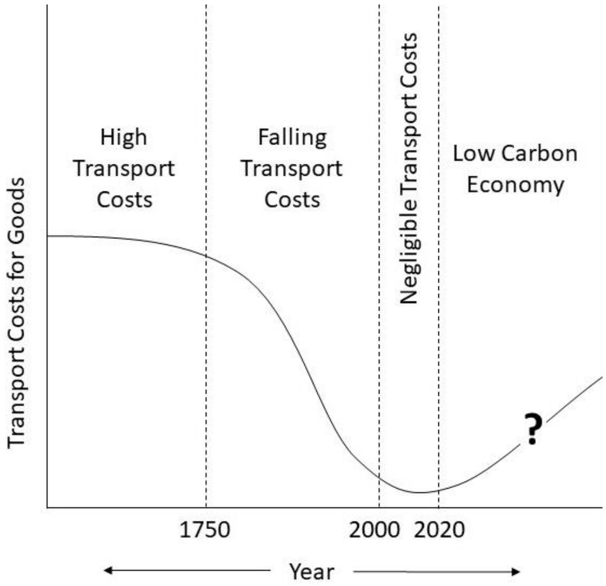
According to Garnaut (2019), the cost of constructing and maintaining long distance high voltage transmission lines may cause transportation costs for energy to exceed the value of the energy itself. Examples include the AUD $20 billion Sun Cable project which proposes to build and link a 22-gigawatt solar farm in northern Australia to Singapore (Macdonald-Smith, 2020; Sun Cable, 2020). The project's proposed distance of 4500 kilometres is modest compared with the distances required to reach Asia's largest economies.

Green hydrogen, produced from the separation of water molecules using clean energy, has been widely touted as a means of exporting renewable power. Unfortunately, hydrogen's bulk and instability make it difficult, expensive and even somewhat dangerous to transport (Gerboni, 2016). Obtaining energy output equivalent to 70 litres of petrol (a full tank in a large car) requires 770 litres of hydrogen weighing approximately 530 kilograms (Koike, Miyagawa, Suzuoki, & Ogasawara, 2012).[4] Energy lost during liquification, about thirty per cent (Sørensen & Spazzafumo, 2018), and transport means that hydrogen could lose half its value between its point of manufacture and destination (Garnaut, 2019). Sørensen and Spazzafumo (2018) estimate that it costs about USD $3 per kilogram to transport hydrogen. To put this in perspective, coal is shipped at about USD $3 per tonne.

This suggests that transport costs matter in a low carbon global economy driven by renewable energy. Figure 1 illustrates changing relative transport costs through time where transport costs for physical goods were once high and a major determinant of industrial location yet have fallen to become negligible by the early 21st Century. In a low carbon economy dependent on renewable energy, transport costs are likely to increase again given the high cost of moving energy (a key input in production).

[4] This is reduced to 315L and 172kg, respectively, when using ammonia.

Figure 1: Transport Costs for Goods over Time



4. Implications for Industrial Location

Renewable energy's asymmetric distribution and high costs of transportation are likely to have a significant impact on the location of energy intensive industrial activity. In a low carbon economy, it may no longer be economically viable to transport energy over vast distances, as was done with fossil fuels. Ceteris paribus, this gives regions with an abundance of low-cost renewable energy resources a competitive advantage in energy intensive forms of industrial activity.

Aluminium and steel production are both energy intensive and examples of activities that may benefit from relocation to regions with surplus low-cost renewable energy resources in a low carbon global economy. Aluminium is critical in the production of lightweight transportation equipment yet its energy intensive smelting process contributes to approximately 3 per cent of global emissions (Home, 2020). In recent years, China's growing share of aluminium production has resulted in an increase to the sector's greenhouse gas emissions. This is likely to come under increasing pressure as firms seek to establish "green" supply chains in the face of more stringent environmental measures (Abnett, 2020; Garnaut, 2019; Home, 2020).

Shifting aluminium production to nations which can economically harness renewable energy resources may not only reduce emissions but costs as renewables become more efficient than fossil fuels (Eckhouse, 2020; Latimer, 2018; Marcacci, 2020). Despite producing just 2.5 per cent of the world's aluminium, Australia is the largest producer of aluminium bauxite (25 per cent) and the second largest producer of alumina (15 per cent) (Natural Resources Canada, 2019). This is due to the cost effectiveness of processing aluminium in Asia.[5] Given the costs of transporting renewable energy and Australia's potential to generate low-cost clean energy, the economics are likely to change for the production of green aluminium. Manufacture of green aluminium in countries like Australia enables firms to competitively access markets with carbon border taxes, such as those proposed by the European Union, and supports the global transition towards a low carbon economy. Transitioning steel production away from major

[5] Australia has traditionally suffered from high electricity and labour costs.

producers such as Korea, China and India, which rely heavily on imported coal for their smelters, will generate similar economic and environmental advantages. Clean steel requires both clean electricity and green hydrogen, both of which are difficult to transport over long distances.

Other energy intensive production, including rare earths that go into batteries and silicon used in computers, is also likely to benefit from relocation to regions with surplus renewable energy resources. Australian energy advisory firm, Energy Quest, supports this view and states that it makes more commercial sense to undertake energy intensive processing onshore than to export both renewable energy and raw materials (Macdonald-Smith, 2020). This is especially true for weight losing processes (Weber, 1909).

The high cost of transporting renewable energy is likely to have a profound impact on our understanding of industrial location in a low carbon economy. Although nations with the potential to generate low-cost renewable energy are in no way guaranteed to become industrial hubs, future locational models would benefit from the inclusion of a trade-off between renewable energy resource location and transport costs. This will complement existing drivers of industrial location including agglomeration forces, factor costs, infrastructure, capital markets and regulation.

A revised perspective of industrial location, which separates the trade-off between transport costs and resource location for renewables and fossil fuels, is presented in Figure 2:

Figure 2: Industrial Location in a Low Carbon Economy

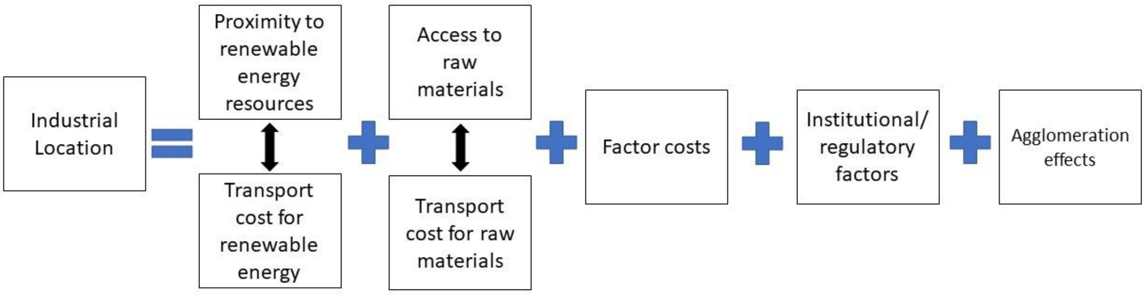


Figure 2 does not seek to portray a new model of industrial location. Rather, the aim of this paper is to demonstrate the importance of separating transport costs for renewable energy from other physical goods such as traditional energy sources (coal, oil and gas), manufactured goods and minerals (iron ore). At present, the low cost of transporting most physical goods has allowed the location of industrial processing hubs to be separated from raw material sources. As such, the literature has argued that the impact of transport costs can almost be removed from industrial location models. This assumption is challenged in a low carbon global economy.

5. Conclusion

Global sentiment to address human induced climate change is growing rapidly. This is facilitated by a transition to clean energy. The competitiveness of wind and solar generation costs, relative to fossil fuels, is leading to a fundamental shift in energy generation technology. Whilst this process in isolation will have minimal impact on industrial location, renewable energy's high transport costs and heterogenous distribution make it far more economical to undertake energy intensive manufacturing and minerals processing adjacent to renewable energy resources. This gives locations able to combine technical expertise, capital and surplus renewable energy resources a competitive advantage in key industrial sectors. Australia's favourable climate, developed capital markets, strong institutions, abundance of mineral resources and educated workforce make it a natural choice for an increased global share of energy intensive industrial activity.

It is expected that sectors which are more energy intensive will benefit most from relocation to regions with low-cost renewable energy. The speed with which this impacts industrial location is largely dependent on government policies and technological change. More stringent environmental regulations and higher carbon border taxes will likely accelerate movement to regions which can produce "green products", whilst reductions to renewable energy transport costs will diminish the importance of natural resource location.

The core thesis of this paper reinforces the importance of understanding comparative advantage as a fluid process (Cypher & Dietz, 1998). Technological change, as reflected in this paper, and government policies shape the strength and direction of a country's competitiveness. It is important to note that the advantage of surplus low-cost renewable energy generation potential must be combined with other factors for a nation to develop its industrial base. Greater adoption of renewable energy resources may also improve the spatial distribution of economic activity.[6] This is due to the high transport costs incurred in moving renewable energy and its abundance outside of urban areas (space intensive nature).

Carbon border taxes are likely to have a disruptive impact on supply chains and corporate profitability. Their imposition will drastically change operating costs and reduce the profitable life of production facilities with limited access to renewable energy resources. Companies which incorporate the dynamics discussed in this paper into their forward planning will be better placed to make effective capital budgeting decisions.

Overall, the influence of transport costs on industrial location is significant in a low carbon economy. Transport costs for renewable energy over long distances have re-emerged as a barrier to the centralisation of industrial activity away from natural resources. Whilst other factors remain in play, locational models will benefit from the inclusion of this dynamic. Future research may seek to better understand the trade-offs presented in this paper by quantitatively modelling the impact of renewable energy transport costs on the industrial location of energy intensive sectors under varying emissions reduction scenarios.

[6] A major challenge in developed economies (Glaeser & Gottlieb, 2009; Glasmeier, Martin, Tyler, & Dorling, 2008).

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